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SEISMOLOGY.—*A symposium on earthquakes.*[1]

1. SEISMOLOGY—A RETROSPECT. F. A. TONDORF, Seismological Observatory, Georgetown University.

Astronomers and geophysicists are generally agreed that the planetary mote on which mankind breathes and moves bespeaks an evolution of a nebulous mass, but the physics of this transmutation is a matter of very persistent dispute with them. Again they evaluate the time of this transformation into the hundreds of millions of years, but their bases of calculation are as diversified as the astounding figures arrived at. These are some of the uncertainties of geology, a science very pertinently christened by someone as the Benjamin. Undoubted, however, it does appear that from the very first incrustations of our globe, fretful apparently at its very existence, the earth gave way to expressions of this anxiety in repeated quiverings. The story, then, of earthquake phenomena is undeniably very ancient. Once people began to tenant our sphere and reckoned time set itself to filing away for posterity items in the archives of the past, its computers were made aware that the flooring beneath their feet was running away from them. Rightly might we expect records to advise us when all of this first happened. Instinctively we turn to the inspired writings, but only to meet with much disappointment. True it is that there we find earthquakes referred to. This under two general connections. First: they may be predicted in prophetical or apocalyptic literature, in which case it is not always certain whether the literal "earth quake" or simply some commotion (moral, social, or physical) is represented by the figure "earthquake." Secondly: a few times earthquakes are mentioned as historical facts. Referred to without historical record,

[1] Papers presented at the 933d meeting of the Philosophical Society of Washington, March 6, 1926.

or even certainly literal use of the word, we find the word "earthquake," in Hebrew *ra'ash*, in Isaiah, chapter 29, verse 6, and in Ezekiel, chapter 3, verses 12–13, chapter 37, verse 7, and chapter 38, verse 19. In the New Testament, where the word appears as "seismos," we find this in Matthew, chapter 24, verse 7, Mark, chapter 13, verse 8, and Luke, chapter 21, verse 11.

In the Apocalypse, or otherwise known Revelation of St. John the Divine, there are five mentions of the word, each prophetic and none certainly literal. As an historical record: In the Book of Kings we read: "earthquake with fire," lightning is probably here referred to. Again in Amos, where the year is not determinable with any accuracy. It is unfortunate that the times in the Old Testament are so equivocal. As regards the earthquake at Horeb, witnessed by Elias and chronicled in the third book of Kings, the 19th chapter, the 12th verse, the passage reads: "And after the earthquake a fire (usual word for lightning)." This took place in the reign of Achab, and, at least, three years after its inception. It is to be noted that the chronologies of the Kings differ by margins of fifty years or even more at the hands of various computers, but the more reliable date for the reign of Achab most probably reached from 873 to 854 B.C. This, therefore, is one of the oldest, if not the oldest scriptural record available in this connection. Others are chronicled to have taken place between the years 789 to 738 and 781 and 743.

It may not be uninteresting for me to mention in this connection that the earthquake accompanying the crucifixion and resurrection would have occurred in the spring (probably) of 28, 29, or 30 A.D. Again the earth shocks felt by the prisoners at Philippi may be assigned, with strong probability, to the year 51 A.D., though from late 50–52 A.D. would be the extreme margins. Before quitting this subject I feel obligated to mention the incident recorded in Numbers, chapter 16, verses 29–34. The engulfing of the rebels, as narrated here, by the fissure of the earth is not explicitly connected with any of the current expressions for "earthquakes;" but, on the other hand, it need not have been of a supernatural character, and if not, it would be most likely referable to a local earthquake or accompanied thereby. In which case this quake would antedate the above. It is to be noted however that the date here would have to be read with a margin of at least a century and one half.

Little wonder, once a people were witness to one of these nerve-racking experiences, that they would make it the topic of their table talk. What they wanted to know was, what it all meant and particularly

curious were they to ascertain when it was likely to reoccur. So the wiser of the communities set themselves up as shock detectors, soon to realize that in the category of sensitive mechanisms, the human body is wholly unreliable. Man, as often as he recognized his shortcoming in the physical world, invoked the machine. Accordingly we read in the Chinese Annals: "In the first year of Yoka, 136 A.D., a Chinese, Choko by name, a smith by trade, hammered out of a lump

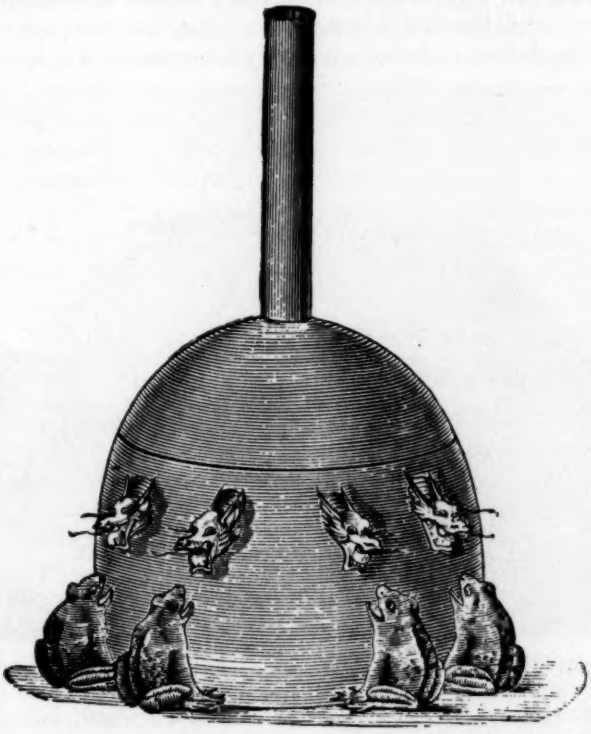

Fig. 1.—First seismoscope, by Choko, 136, A.D.

of copper an instrument to which he or some one of his admirers gave the name of seismoscope (Fig. 1). The tale goes on to say: "Once upon a time a dragon dropped its ball without any earthquake having been observed, and the people, therefore, thought the instrument of no use, but after two or three days a notice came saying that a shock had taken place at Rosei. Hearing of this, those who doubted the use of the instrument began to believe in it again. After this ingenious

instrument had been invented, the Chinese government wisely appointed a secretary to make observations on earthquakes." Passing strange it is that in the history of scientific development there seems to have been a stagnation persisting from the very earliest findings till deep into the middle ages. Two striking instances are electricity and magnetism. Add to these investigations in earth shocks. For from the time of our Chinese friend till 1703 not one advance had been made instrumentally. Then it was that a French priest, De Haute Feuille, featured the first improvement (Fig. 2). Not only did he claim for his device a greater sensitivity than that of Choko, because

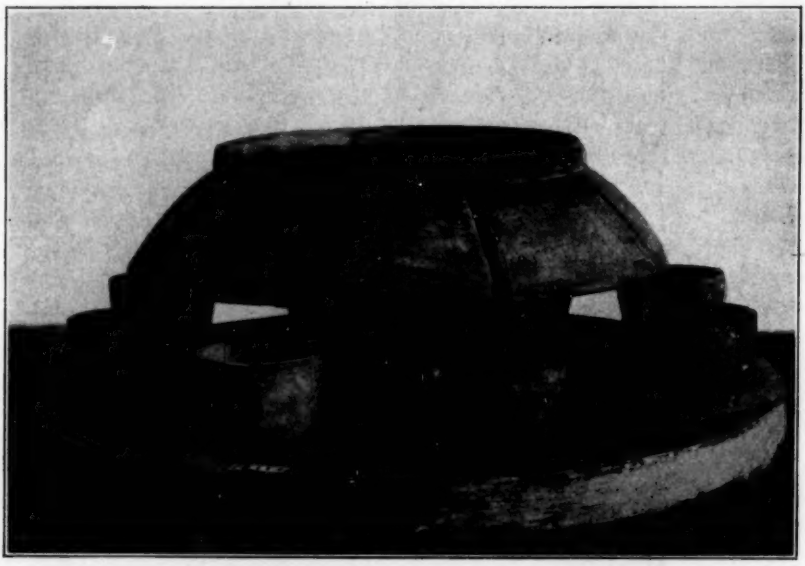

Fig. 2.—De Haute Feuille's modification of Choko's seismoscope, 1703.

of the substitution of mercury for the metal spheres but also the additional asset of rating the intensity of the quake in terms of the displaced fluid.

It might be instructive to indicate all of the contraptions for recording tremors carrying us from what I might style the period of qualitative study of earthquakes into the quantitative, but time prevents. Close to the end of the last century a band of English geologists, amongst whom I may mention such names as Milne, Ewing, Perry, Knott, and Gray, made their way to Japan and there, in collaboration with the Japanese geophysicists, put together the first of the scientific

seismographs. Ewing is accredited with the first horizontal seismograph in 1879. The stationary mass of this machine was 25 kg. and the length of the suspension 6.8 meters. Just one year later Gray announced his vertical instrument. Short functionings of these instruments early made it apparent that the earth's autographs were vitiated by a tendency of the swinging mass to take up its own natural period of oscillation, a condition which becomes very exaggerated where the period of the earthquake vibrations approximate that of the pendular mass. Wegener, an associate of Gray, first took notice of this. Gray very promptly attacked the problem of eliminating these vitiating elements and this through friction. Rood, an American geologist, first applied liquid damping. Toepler followed with air damping, a method quite popular even today. Galitzin's latest interference is magnetic. Possibly this is the most efficient. Brassart, in 1886, gave to science the first double component machine. This was of the heavy pendulum type. A very marked departure in earthquake instrument construction dates back to 1892 when Milne showed that a heavy mass is not an essential feature of an efficient seismometer. In 1894, on the suggestion of the same Milne, the photographic sheet became a close competitor of the sooted parchment. Galitzin's magnetic registration and Wood-Anderson's torsion pedulum close the story of the earthquake instruments to date.

Investigations into the transmission of earth movements through the earth's capsule were first launched by Young. His was the mind that suggested that the propagation was akin to that of sound waves in air. Gay-Lussac concurred. In 1846 Mallet first put the transverse waves into competition, though he by no means made it clear that two types of undulations were distinct, to wit the longitudinal and transversal, or compressional and distortional. This was reserved for Wertheim. Milne, following his instrumental findings, placed a definite imprimatur on these interpretations. Wiechert, in 1899, first read out of grams the reflected longitudinal wave and Zoeppritz first the transversal waves once reflected. Wiechert seems to have first diagnosed the long or Raleigh waves which many years antecedently Ewing had mistaken for the transversal. Seismologists have not as yet bequeathed us all the wealth of the gram.

Following the complete identification of these elastic undulations, the seismologist, knowing what he was after, had to establish their running record. To Wiechert and Zoeppritz credit is due for the first reliable time curves, reading up to 12,000 kilometers, though earlier attempts at these had been made by Schmidt, Milne, Benndorf, and

Oldham. In 1912 Wegener edited charts for distances in excess of 11,000 kilometers. Others followed in quick succession. These by Gutenberg, Meisner, Mohorovicic and Angenheister. There is still a readiness on the part of geophysicists to accept even more reliable tables. One might suspect that attempts at fixing the exact centers of quakes were very early. Far from it. Mallet appears to have been the first to establish the geography of these happenings from isoseismal lines. Where reliable observers are available, this method still qualifies. No further back than 1911 did Milne work out his first group of epicenters covering quakes between the years 1899–1903, on the basis of triangulation. A second group appeared in 1912 spanning the years 1904–1909. The work then fell to the lot of Turner who published centers for 1911 and 1912. Strassburg pledged itself to the work in 1918 but due to the world war the results are now some four years in arrears.

Every people seem to have had a secret formula for solving the problem of earthquake occurrences. One or other may be mentioned. The ancient Greeks held resentful Zeus responsible for these visitations. The Babylonians attempted to read their wherefore in the stars. The inhabitants of the West Carolinian Islands fancied they heard in them the stampeding of giant animals against the earth's crust. Others deciphered them as the rappings of warning spooks. Over against these unique, not to say, grotesque ravings, we have the more reserved interpretations of the older philosophers. Pythagoras, 580 B.C., attributed earthquakes to underground fires therein anticipating volcanic earthquake history. Metrodorus, a pupil of Democritus, 460 B.C., made a guess at a theory which pressed hard in on the prevailing theory of today. He said: One mass of the earth may sink, following gravity, while another has to rise to maintain equilibration. Epicurus, 341 B.C., favored the notion, afterwards sponsored by Germans, that the ground water dissolved out certain geological materials and that the overhanging dome, for want of support, collapsed. Aristotle, 384 B.C., conceived earth tremors to be brought about by the attempted escape of air imprisoned within subterranean cavities. Cardano, mathematician and philosopher, about the middle of the 16th century, looking on the earth's interior as one gigantic crucible, saw therein sulphur, bitumen, and saltpeter chemically interacting and the energy liberated causing havoc to the abutting walls of the laboratory. Alexander von Humbolt orthodoxly observed that though there were earthquakes usually connected with volcanic eruptions, such were distinctly in the minority as compared with the

devastating quakes of history. He conceived, therefore, the volcanoes to be safety-valves for the pent-up gases imprisoned within the earth. A return here to the Aristotelian doctrine. Here I must mention Mallet, an English inventor of machines of war. When in 1857 a destructive quake razed the kingdom of Naples, he applied to the Royal Society for a grant for research along this quake. As he was deemed qualified for such studies because of his familiarity with explosives, the allotment was made with the result that the bookshelves of the seismo ogists were graced with two new volumes, entitled "The Neapolitan Earthquake." This in 1857. Mallet, so we read in these tomes, agreeing with Aristotle on the fundamentals of his theory, applied thereto the findings of the Dutch physicist, Huygens, on the travel of harmonic disturbances in different media. With these embellishments Mallet christens the theory the centrum theory. For the first time, too, we meet with the terms, now bywords with the seismologists, centrum, epicenter. About fifty years was to be its lifetime. The great quake in the Neo Valley, Japan, 1890, set geologists to doubting it. Photographs taken of the territory showing macroseismal movements indicated fractures running for miles across the country and that along these seams of rupture the land had seesawed, rising in one point to a maximum height of eight feet, while in some places, though neither side had been raised or lowered in reference to the other, the two sides had slipped by each other in opposite directions. Six years following this catastrophe there occurred the heavy quake in Assam. Three fractures were located in a study of a restricted portion of the affected area and a vertical displacement of thirty-five feet. Oldham published a memoir in which he contended that one plane of fracture was clearly a thrust on a plane of low angle to the horizon. In 1906 Tarr and Martin contributed an article to the Bulletin of the Geological Society of American in which they showed that following the severe quake of September, 1899 in Yukutat Bay, there were marked depressions in the coast line and elevations on land amounting to 16 meters. This they attributed to mountain growth with vertical adjustments between the large blocks within a fault mosaic. In 1907 Mr. Willard Johnson made a field survey of the Owens Valley quake of 1872 and for the first time an accurate map was prepared of a fault network suffering adjustment at the time of earth movements. With such imprimaturs the so-called tectonic theory of earthquake has grown until today it is a dogma of the seismic school.

The researches of the past half century and particularly of the past decade have dowered seismology with a wealth of information. These

investigations have been stimulated through such agencies as the British Association Seismology Committee, the International Seismological Society, with headquarters in Strassburg, the Imperial Earthquake Investigations Committee, Tokio, Japan, the Seismological Society of America, and the Carnegie Institution of Washington. Besides, the several governments the world over have lent most liberal encouragement to this work. Most recently have our own United States officially authorized seismological researches and designated the Coast and Geodetic Survey to execute them. The authorities have so auspiciously inaugurated this new activity that it is quite apparent that our country in the very near future will add many more interesting pages to the history of this most important of the sciences.

2. OUTSTANDING PROBLEMS IN SEISMOLOGY. N. H. HECK, U. S. Coast and Geodetic Survey.

The outstanding problem in seismology is to develop a future worthy of the past. There might appear to be no reason to feel any doubt, and yet such a future will not be assured without special effort. A few days ago I read a review of the art conditions in various countries which was rather critical of present conditions. The critic overlooked the fact that probably many of the men who would have been the outstanding or arriving artists now were killed or wounded in the war. The same thing would appear to apply to seismologists especially in the countries which were most active before the war.

I do not intend to discuss details but only the outstanding points in the various problems which are now occupying the attention of seismologists. Each subject could be the basis for several papers.

An apparently simple problem is one which many seismologists have given up in despair and yet which apparently cannot be dispensed with,—the determination of isoseismal lines through appraisal of intensity by observers. This, of course, applies only to earthquakes whose effects are felt or visible.

The elements of the problem include: inability of the average man to tell his experiences accurately, especially when disturbed; difficulty in securing proper distribution of competent observers; actual changes in effects from place to place, as between rock and alluvial land; disagreement between two observers at the same place; and difficulties in adopting a scale of intensity which will fit all the observations.

The solution is necessary, as in most cases there is no other practical means for determining the area disturbed and distribution of the in-

tensity. At present the effort is to get the largest possible number of competent persons to report; the Coast and Geodetic Survey has adopted a form which guides the reply, but which leaves it free for the observer to state his own impressions. He is not asked to estimate the intensity. It has been proposed to form special local organizations in earthquake regions for the purpose of making accurate reports. The Weather Bureau has taken an active part in this work in the past, and is continuing to do so. With the best possible results, the problem is much like that of plotting magnetic lines for a region of magnetic disturbance, though with good judgment reasonably satisfactory results are obtainable.

It has been made clear that instrumental development is the necessary background. Adoption of good instruments in this country is most important. The Wood-Anderson seismometer seems to give considerable promise as a teleseismic instrument, and the test now being made under observatory conditions at the Coast and Geodetic magnetic observatory at Tucson, Arizona, is likely to be productive of much benefit.

Most of you have had occasion to use apparatus in which an essential feature is the uniform rotation of a cylinder. This was not well accomplished in many of the best European types of instruments. The need for such apparatus developed during the war and it is now possible to have rotation of any desired accuracy. The problem is now to secure the result with minimum cost and minimum complication of apparatus. It will be seen that this matter of accurate time is vital to many parts of the study. As soon as an entirely satisfactory apparatus of low cost is developed for the Wood-Anderson instrument, it is going to be possible to have widespread distribution of good seismographs.

One of the outstanding needs is the operation of vertical instruments. Such records are indispensable, but at present there is no suitable instrument which can be operated with a moderate degree of attention. Father Tondorf is making a wonderful contribution at Georgetown University by operating his Galitzin vertical, but he will admit that it is a difficult instrument to install, operate and keep in order. Until we have more vertical instruments, certain urgently needed studies must be postponed.

Assume that we have satisfactory instruments, what are we going to get out of them? The results that we are going to get depend both on ability to interpret the seismogram and to completely develop the underlying theory. A great deal of work has been done on both of

these problems during the present century. Just as in every field of science, as the significance of various phases has been established on apparently good evidence, there have been some who have refused to accept the conclusions and have forced the accumulation of evidence till it was overwhelming. This is a proper course, though in every case the critics should be those who are themselves making contributions to seismology.

The *P* and *S* waves are now generally accepted as having definite significance, but Wiechert, as recently as 1903, had difficulty in securing the acceptance of the *S* wave as a transverse wave following nearly, if not quite the same path as the longitudinal *P* wave. It took much study to develop and recognize the various reflected waves and this process is still going on. The complications of the subject can be readily recognized when it is considered that at each reflecting surface there are really five possibilities, in case the approaching wave strikes the surface obliquely, though all of them do not occur in every case.

Suppose the incident wave is longitudinal. There may then be a reflected longitudinal and a reflected transverse, each taking a different path; also a transmitted longitudinal and transverse, each taking a different path. There will also be Rayleigh waves transmitted along the surface. Though ordinarily in the case of the surface, not more than three reflections have been recognized, the possible number of reflected waves is very great and certain series may appear under some conditions and another set under others. It is evident that this is a problem worthy of the best efforts of seismologists. Though it is far from being fully solved, it is significant of the new spirit in this country that Dr. James B. Macelwane, head of the Jesuit Seismological Association, is at present engaged in preparing tables which extend the work of Klotz, Visser, Gutenburg and others so that we may take into account a large number of phases. He is preparing convenient tables to make this possible. The method is to determine the approximate distance of epicenter, then enter the tables and take out the time of arrival of the phases given. Then make an independent study of the seismogram and set down the phases observed. There should, with good records, be an agreement of perhaps eighty per cent of the phases when the correct distance has been adopted. This makes it possible to obtain much greater distances accurately than the previous tables permitted. The unidentified twenty per cent of the phases may be either non-existent or not yet identified. This shows the need for further investigation.

The tables cover average conditions. At some stations average

conditions do not give good agreement. This seems to be unquestionably true of the records obtained at the Honolulu Magnetic observatory. An investigation is in progress to establish this fact beyond argument and discuss possible explanations. In general, waves reach this station considerably in advance of the time required by any existing theory.

Long waves, though the most impressive parts of the seismogram, are less important for obtaining distance than for determining intensity. They are extremely complex and have only in part responded to mathematical treatment. A mathematical physicist has an ample field for his effort.

To obtain the intensity of the ground movement, it is necessary to obtain from the seismogram the acceleration and the intensity. Determination of the acceleration, which is the factor needed by designers of structures and which may be also used in placing isoseismal lines, is an essential operation. The acceleration can be obtained from the period and the amplitude. With well-designed seismographs the period of the recorded wave is practically equal to that of the earth wave, but the instrument, for practical reasons, is designed to give a much greater amplitude than that of the earth's movement. The magnification is calculated from the period of the earth wave and instrumental constants, and the amplitude of the earth movement may thus be known. With an undamped seismograph magnification cannot be determined when the period is the same or nearly the same as the natural period of the instrument on account of resonance. This is a frequent occurrence in the case of the long wave.

The theory of wave transmission has been investigated mathematically in quite a thorough manner but parts, even of the generally accepted theories, do not satisfy all seismologists and there is a vast amount of debatable ground for future investigation.

A knowledge of the direction of the earth vibrations (in three dimensions) is necessary to determine depth of focus. The problem of maximum depth of focus, as well as depth of a given earthquake, is naturally one of great interest.

The establishment of isostasy would seem to make it necessary that all earthquakes should occur above the depth of compensation. Geodesists are therefore interested in more accurate determinations of depth of focus. This will require more accurate timing of arrival of phases than heretofore and the recording apparatus developed by Wood and Anderson will help to solve this problem. The stations now being established by the Carnegie Institution in California should

give valuable evidence on this question of depth, the only possible difficulty being that most of the earthquakes there are probably relatively shallow, as evidenced by the effect on the surface of the earth.

Certain phases appear on seismograms which can be explained only on the assumption that there are reflecting layers at the depth of 60 kilometers and 2900 kilometers, respectively. These layers are established beyond a doubt and there is good evidence for other such layers. The 2900 kilometer layer is also arrived at by other methods, such as those used in the studies of the Geophysical Laboratory. The physical significance of these surfaces of discontinuity afford an interesting problem in physics.

The phenomenon of crustal creep seems to be established for regions such as California where earthquakes are known to be of not infrequent occurrence. The measurement of the amount of change of positions both horizontally and vertically by geodetic methods has now been carried to the point where the determination of the manner in which strains develop and are released may be possible.

The Coast and Geodetic Survey is, by the nature of its other work, especially attracted to consideration of the submarine earthquake. Its accurate surveys along our coasts are going to make it possible to determine accurately the changes due to earthquakes. An important illustration of this has been recently found in investigation of the records. In 1914 an accurate survey was made by modern methods of a shoal near the Cuyo Islands, Sulu Sea, Philippine Islands. Eighteen months later it was found that part of the shoal had dropped through at least 100 feet. An earthquake was recorded about halfway between the two surveys. This is probably the only case where change has been proved by comparison of two modern hydrographic surveys, each of the same standard and with control of positions by high-grade triangulation determination of the objects used. The details of this case are of more interest to geologists, but there is a definite relation between such cases and the broad questions of geophysics.

I have left a number of important problems unmentioned, but believe that I have described enough of the problems to show the great field of investigation that is open to the seismologist, which will not only be of scientific value but will have a direct bearing on the solution of some very practical problems of preservation of life and property.

3. EARTHQUAKES FROM THE ISOSTATIC VIEWPOINT. WILLIAM BOWIE, U. S. Coast and Geodetic Survey.

In attacking problems relating to the structure of the earth's crust and the processes which change surface features, it is desirable that all available data be used. One of the earth problems awaiting solution which is receiving a great deal of attention to-day is the earthquake. The data resulting from the isostatic investigations should prove of value in studying this phenomenon.

It is not possible, in this short paper, to cover the subject of isostasy. What is known of that condition of the earth's crust is set forth in many reports and papers, readily available, which have appeared in recent years. Here we need merely accept isostasy as a scientific principle and see what is its probable relation to those processes which are at work within the earth to rupture rock and cause the tremors known as earthquakes.

The isostatic investigations seem to indicate very clearly that the depth to which the isostatic compensation extends is about 60 miles below sea level. That depth is not a fixed one, always the same in different places. The derived depth of 60 miles from geodetic data is an average one. The compensation, in some places, may extend to a greater depth and at others may not reach so deep below the outer surface of the earth.

It has been shown, with some degree of exactness, that the compensation of topographic features is a somewhat local phenomenon, but it is uncertain as to whether or not the compensation extends horizontally 25, 50, or some other number of miles from the feature. A test of whether or not strictly local or regionally distributed compensation most nearly eliminates the isostatic anomalies was reported on in Special Publication No. 10 of the U. S. Coast and Geodetic Survey. Regional distribution, out to a distance of about 37 miles from topographic features, eliminated the anomalies about as well as strictly local compensation. When the compensation was distributed regionally to a distance of about 104 miles from the topographic feature, the anomalies were larger, on an average, than for the other methods of distribution.

A test was made to show the mass of a topographic feature which might escape isostatic adjustment.[1] The results seem to indicate that any topographic feature, having an average thickness of 3000 feet and a radius of about 18 miles is, at least largely, compensated.

[1] See p. 34, Special Publication No. 99, U. S. Coast and Geodetic Survey.

The crust below all classes of topography, whether high, low or intermediate in elevation, is in isostatic equilibrium. This is true for the various geological formations, whether old, recent or intermediate. The isostatic test has been made for a number of regions; these include the whole of the United States, southern Canada, the Mackenzie River Valley in Canada, Holland, western Siberia, the Alps, India, the Solomon Islands and their vicinity, and Spain. In every case the crust beneath the geodetic stations used has been found to be closely in equilibrium. We are justified I think from the results of these tests in predicting that tests in other regions will show that the crust beneath them is also in isostatic equilibrium.

All mountain systems existing to-day occupy areas which previous to the uplifts were areas of heavy sedimentation. How can an area that was once low, subjected to 10,000 feet or more of sediments and, presumably, in isostatic equilibrium (for all sedimentary areas to-day are in that condition) become an area of uplift, with an average height of topography of a mile or more, with the crust below still in isostatic equilibrium? The mountain mass is not an extra load on the subcrustal base beneath the mountain area. If it were so, surely this condition would be detected by the deflections of the vertical and the values of gravity at stations in the vicinity of the mountains.

There are two ways in which a mountain system can be formed in a sedimentary area and still not have the mass as an extra load. One is to have the crust of the earth thicken beneath the mountain area with roots projecting into subcrustal space. These roots would just balance, by their deficiency in density, the mass that forms above sea level. This is what is called the "roots of mountains theory," advanced by Osmond Fisher a number of years ago. Fisher was following the equilibrium ideas of Airy.

The second method would be to have a decrease in the density of the crustal material beneath the sediments, resulting in an increase in the volume. The material would tend to expand in all directions but it could not go down nor would it be able to push sidewise to any extent. The line of least resistance would be upward and this is the direction in which the material goes. This latter theory is based on the idea of Pratt.

One of these theories must be true, but which one no one knows. But the indications seem to be that the Pratt idea is much the stronger of the two. The "roots of mountains" theory has a number of weak points which have not been cleared away by its advocates. I strongly advocate the Pratt idea and the statements made in this paper are based on it.

We seem to be left, then, with the earth's crust, approximately 60 miles in thickness, in almost perfect isostatic equilibrium. The topographic features are compensated by deficiencies or excesses of density in the crustal material in the vicinity of the features. This compensation may extend horizontally to a distance of 20, 30, or possibly some greater number of miles, from the feature, but it is probable that the regional distribution of density does not extend out as far as 100 miles from a topographic feature. A topographic feature, having dimensions equivalent to 3000 feet in average thickness, with a radius of 18 miles is at least largely compensated. The mountain systems occupy areas which in a previous period had been subjected to heavy sedimentation. Those areas of heavy sedimentation were along the margins of oceans or of inland seas.

We have, in the above, information and data of great importance in the study of earthquakes but we have additional information which must be considered. This is that the isostatic condition of the earth's crust is probably maintained while tremendous loads of material are shifted over the earth's surface. The rate of erosion in the United States is such that one foot, on the average, would be denuded from the 3,000,000 square miles of our area in 9000 years. This is a rate of half a mile of erosion in 20,000,000 or 30,000,000 years. The average elevation of the United States is about 2500 feet and at the above rate most of this mass would be denuded in a comparatively short time. But we must remember that, as erosion takes place, the isostatic equilibrium is not permanently disturbed. If 1000 feet of material were eroded from an area, undoubtedly the original crust below would be lighter than it had been before, but the pendulums and deflection of the vertical stations do not show that an area of rapid erosion is out of equilibrium. We must conclude that, as the material is eroded from the surface, there is a transfer of subcrustal material into the crustal space to offset the erosion. We do not know the density of the subcrustal material but it is reasonable to assume that it is 10 per cent or more denser than the surface material which is approximately 2.7. In any event, in order to base-level an area, it would be necessary to erode from it several times as much material as appeared in the original mountain mass. Under the influence of erosion, the crustal material below is brought into higher and, presumably, colder regions. This coming up of the crust undoubtedly results in fractures in the crustal materials and especially in the cold rock near the surface, thus causing earthquakes. It is probable that this process was involved in the earthquake in Montana during the summer of 1925.

As material is laid down along the margins of an ocean or an inland sea, the crust below sinks under the added weight, but it would appear that only a moderate amount of sediments could be laid down in shallow water in any particular region because of differences in density of the sedimentary material and the subcrustal material. It is probable that the subcrustal material is at least 20 per cent denser than the unconsolidated sediments. We have, however, evidence of many thousands of feet of sediments having been laid down in shallow water. We must, therefore, conclude that there is a sinking of the crustal material, independent of the weight of sediments.

An analysis of the situation leads us to believe that this independent sinking is due to cooling off of the crustal material which was uplifted during a prior period of erosion. As was mentioned earlier, the crustal material below an erosion area rises to colder regions. Eventually that material will cool down to the temperature normal to those new places; then some physical or chemical reaction probably takes place which contracts the crustal material which had been uplifted. A sinking of the surface would take place, due to this contraction, and a synclinorium would be formed into which sediments are deposited. Does it not appear, therefore, that any area that is receiving or has received great masses of sediment all laid down in shallow waters, was previously a mountain area, or at least one of high elevation, from which much material had been eroded?

As the material of the crust which had been carried upward during erosion contracts, the contraction would tend to take place in all directions. This would probably make rifts within the contracting material and between that material and the unaffected crust to the sides, but the crustal material is not strong enough to maintain a rift extending to a great depth (what depth we do not know). It would appear, therefore, that there would be a horizontal movement to fill any deep rifts that might have opened. It would seem probable that there would be some slow movement of material, resulting in distortion without fracture, but it seems logical to assume that some of the contraction would result in rifting and that this would give rise to earthquakes. As the sediments are laid down on the crust the weight of this added material will push down the crustal material beneath it. This will force aside subcrustal material equal in mass to the added weight. In addition to the earthquakes due to independent sinking, it would seem to be most probable that earthquakes in sedimentary areas are also caused by the weight of sediments pressing the crust down. Some of the pressing down from the weight of the sediments

will take place so slowly that the crustal material will yield to the stresses without fracture. At times, however, the sediments will accumulate more rapidly than the ability of the crust to assume new shapes and forms without rupture or crushing. In these cases the material will be strained beyond the elastic limit and a break will occur, causing an earthquake. It is probable that about one-fifth of the lowering of the base of the sediments is due to the contraction of the crust below, and four-fifths to the sinking caused by the weight of the sediments.

As the sediments are laid down along the margins of an ocean or an inland sea and the crust sinks beneath, the crustal material will be carried down into hotter regions. The sediments in some cases are as much as five or more miles in thickness and it is reasonable to suppose that the crustal material beneath these sediments will be carried down approximately an equal amount. When the material assumes the temperature of its new position, there will be a chemical or physical reaction, or a combination of the two, which will expand the crustal material. There will also be the ordinary thermal expansion. It is possible that the mountains and plateaus are formed by the expansion of the crustal material below them. In fact, it is most probable that this is true if the Pratt equilibrium idea is the correct one.

In the process of uplift to form the mountain system, cubical expansion would tend to operate, but the material cannot go down nor sidewise, therefore the movement is upward. There would be much crushing of material during upward movement and in the confining of the movement to a single direction. Much of the distortion of strata and the horizontal displacement as observed in an uplifted area may be merely incidents to the vertical movement. In any event this expansion of material to cause mountains or plateaus will undoubtedly rupture rock near the surface and give us earthquakes.

There are other earthquakes than those mentioned above. These are caused by the explosions occurring in the vicinity of volcanoes. These earthquakes, as a rule, are not very heavy ones.

With isostasy established as a scientific principle, we are forced to conclude that the subcrustal material is plastic to long continued stresses or, at least, that it has very low residual rigidity. It would therefore seem to be most probable that the subcrustal material would yield without fracture to the stresses resulting from shifting of loads on the earth's surface. This leads us to believe that the earthquake must be a phenomenon confined to crustal material. Since the crust is approximately 60 miles in thickness, we should not expect the epi-

centers of earthquakes to be at a greater depth than 60 miles below sea level. The late Prof. Omori, the famous seismologist of Japan, made a statement in one of his papers that he had not located any epicenters at a greater depth than about 27 kilometers. This fits in with the isostatic principle. The determination of depths of epicenters is a subject which is receiving a great deal of attention by seismologists and we shall look forward with interest to the results obtained by their studies.

Conclusions: Based on what has been said above, we must postulate that we have several causes of earthquakes. Since the theory of isostasy has been proved and may now be called the principle of isostasy, we must not ignore the equilibrium of the earth's crust in earthquake studies. It seems probable that the isostatic equilibrium of the crust has obtained throughout the sedimentary age of the earth. Earthquakes are, apparently, due (on the isostatic principle) to the maintenance of isostatic equilibrium during erosion and sedimentation, the expansion of the crustal material which has been thrust downward under sedimentation into hotter spaces, and the contraction of the crustal material which has been pushed upward into colder spaces under areas of erosion. These would appear to be the major causes of earthquakes. In addition, there are the volcanic earthquakes of more or less local character and of minor importance.

4. Difficulties in the Study of Local Earth Movements. Arthur L. Day, Geophysical Laboratory.

In 1905 I was sent officially to England to confer with Sir John Milne in regard to some contemplated developments in the study of earth movements, and visited him at that time at his place at Shide on the Isle of Wight, where he had a number of seismographs set up and operating. He was then of course nearing the close of his career.

Milne, at that time, was a gentleman farmer by environment, and had become the world's foremost student of seismology through the pursuit of his chief avocation. He intimated that it was a gentleman's privilege to choose his pleasures as he wished, and this was his choice. I was shown his equipment with much enthusiasm. Without explanatory preface he told me then and there the cause of two-thirds of the recorded earthquakes, namely, spiders in the instrument case.

A little later Mr. Gutenberg, who stands in the very front rank of seismologists today, was able to explain a portion of the remaining ones. It appears that in the great laboratory at Göttingen which has become

familiar to you all through the work of Wiechert, earthquakes were at one time of frequent occurrence whenever a certain outside window was open. They did not persist when it was closed.

Notwithstanding these historic episodes, or perhaps occasionally because of them, the study of earthquakes is a thoroughly serious business, as all of those distinguished men who have sought to approach the subject quantitatively have discovered, whether the search be directed to the causes of local earthquakes or to the constitution of the earth's interior mass.

It is quite possible by the use of these refined methods, which have been described to you so clearly by Father Tondorf, to pick up earth vibrations of many different vibration periods beginning as low as from four to seven or eight-tenths of a second. These short waves form a class by themselves, which was first seriously studied by the Göttingen group and originally ascribed by them to the waves of the North Sea. One early difficulty lay in the fact that the direction in which the sea lay was not always the direction from which these waves had come according to the seismograph record. Afterward Gutenberg became interested, as most of you know, to try to fix upon some other natural phenomenon which might prove adequate to explain these short-wave disturbances. He studied the relation between the movements indicated by his instruments and the beating of the waves upon the rock-bound coast of Norway, the varying barometric pressure, the wind-velocity of the storms which visited the region, and finally with different varieties of traffic at various distances. In general these discussions, which came out some ten years ago and were very generally participated in by the seismologists at work at that time, established the fact that probably all of these causes have some share in the so-called short group of waves, but the actual share of each of them was not then and is not now established. It is probably true that the waves of the sea had some share in these short-wave disturbances because the instruments set up on the Island of Helgoland in the North Sea plainly show such impulses of appropriate period. There has also been for many years a very well-equipped laboratory upon one of the Islands of the Samoan group where earth movements of period appropriate to the sea waves have been recorded. Nevertheless the matter is not cleared up and disturbing movements of unknown origin still pursue the student of short-period earth movements, i.e., of local earthquakes.

In California we have on the west coast a mountain range (the Coast Range) which geologically is quite unstable, and has been

likened by Lawson to a door which rises and falls on a hinge (the Sierra Nevada mountains); which has swung below the sea at least a mile and above the sea by an amount equal to its present elevation, five or six different times in the course of its geologic history, as is evidenced by alternate depositions of marine sediments and the sand and clay accumulations from surface erosion. Out of the geologic history of the region therefore we know that tectonic forces have lately been and probably still are locally active,—this is one of the chief reasons why the Carnegie Institution has selected it for the earthquake studies now in progress there. It is not a region like a volcanic centre in which occur only local earthquakes which are felt but a short distance away, but it is a region of frequent and powerful local movement. The epicenter of the 1906 earthquake extended over 190 miles of land, and probably more of ocean floor, as you undoubtedly recall. Likewise the Santa Barbara earthquake of the past summer, though local in point of damage to buildings, was complicated and possibly far reaching in its effect upon geologic structures. Its source has been traced to two faults, one of which is perpendicular, at the base of the Santa Ynez Mountains, the other is a thrust fault from the direction of the sea. The two intersected at a comparatively narrow angle within which stood the more thickly settled portion of the city of Santa Barbara. Both active faults have been located by investigation since the earthquake. We are therefore confronting here local tectonic movements of considerable severity and complication and may expect others.

There is one other limitation which confronts the student of local earth movements which is neither attributable to spiders nor to air draughts, to sea waves nor to storms, there are great differences in the kind of crustal movement recorded, which vary with the sort of foundation the instrument happens to be standing on. The most convincing illustration of it is to be found in the fact that the greatest destruction always occurs on filled land. Reid has developed a theory of the movement of masses of alluvium contained in a rigid bowl to which forces are applied from without. It is contained in the second volume of the Report of the California Earthquake Commission published by the Carnegie Institution of Washington in 1908. In illustration of this Professor Rogers of Stanford University, during his study of the 1906 earthquake, built a box a meter or more long and half as wide, filled it with wet sand and attached it by a horizontal crank shaft to a wheel, so as to be shaken to and fro with a measured period and amplitude, in order to see what relation the movement of the sand might

bear to the movement of the box containing it.[1] This relative movement is best shown by Rogers' curves, reproduced in Fig. 1, but the amplitude of movement of the sand was always greater than that of the containing vessel, usually about twice as great, and was relatively much greater when its water content was increased. It is usual to interpret this observation by pointing out the danger to all structures erected on filled or unconsolidated or water-soaked ground. It might be equally pertinent to recognize its bearing upon attempts to interpret seismograph movements recorded at points similarly exposed. With the study of local earthquakes particularly is coupled the need for full geological knowledge of the region and its ground-

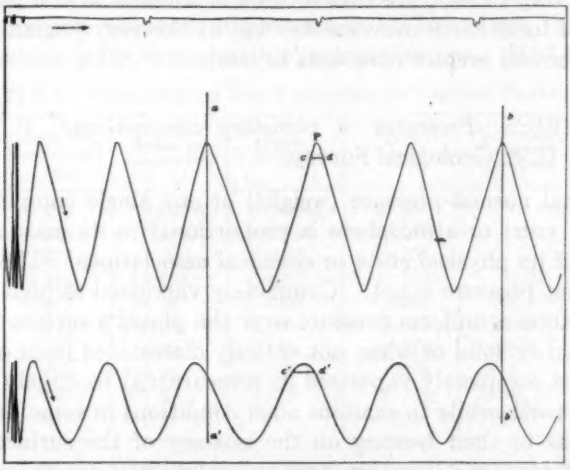

Fig. 1.—Upper curve represents actual movement of the sand. Lower curve represents actual movement of the containing box.

water relations lest the earth-wave itself may have suffered unsuspected distortion somewhere between epicentre and instrument. There are even many seismometers which for one reason or another do not rest upon igneous-rock foundations and contrariwise few earthquakes have their origin in homogeneous igneous rock.

There is a similar situation in the application of the Rossi-Forel Scale and the determination of isoseismal lines which perhaps found expression in some of the difficulties which Commander Heck has just portrayed to you. Such an arbitrary scale of intensities may be worth

[1] F. J. ROGERS in Report of the California Earthquake Commission (A. C. LAWSON, Chairman), Carnegie Inst. Wash. Pub. No. 87, 1: 326, 1908.

much or little, according to the experience of the man who applies it. A chimney on a hillside, or in a valley adjacent, will suffer quite differently in the same earth movement. Indeed at Santa Barbara the destruction in the plain at State Street was rated at IX or X, Rossi-Forel, while the hillside, no more than two or three city blocks distant, showed no damage which could be rated higher than V or VI, even though located between the same portions of the active faults and somewhat nearer to one of them (Santa Ynez) than is State Street. Such crude classification partakes but little of a quantitative character and seismograph tracings are frequently subject to similar limitations, particularly in the records of local earthquakes.

These, very briefly, are difficulties which stand in the path of the student of local earth movements, and at the very beginning of the path, other and greater ones wait beyond.

GEOPHYSICS—*Pressures in planetary atmospheres.*[1] P. G. NUTTING, U. S. Geological Survey.

The total normal pressure (weight) of any single component of a planetary crust or atmosphere is proportional to its mass and independent of its physical state or chemical associations. The distribution of that pressure is not. Completely vaporized at high temperatures it exerts a uniform pressure over the planet's surface but when partly fluid or solid or when not entirely dissociated from other substances not completely vaporized its pressure may be largely localized. It seems worth while to examine such conditions in some detail, particularly as to their bearing on the isostasy of the surface. Many numerical data on vapor pressures and solubilities are lacking but the argument is fairly simple.

Take the case of water on the earth for example. The critical temperature is about 374°C. and the critical pressure 217.8 atmospheres, pressures being expressed in atmospheres and temperatures in °C. on the absolute scale (Data of Holborn 1919). The water of the earth covers 70.82 per cent of its surface of 196,950,000 sq. miles to a mean depth of 3681 meters or 2.287 miles (Data supplied by U. S. Coast Survey 1926). The waters of rivers, lakes, the atmosphere, polar ice, ground waters and combined waters are quite negligible by comparison. The oceans therefore contain sufficient water to cover the entire earth to a uniform depth of 2607 meters. At temperatures exceeding 374°C. all waters must be atmospheric and con-

[1] Received March 21, 1926.

tribute a fixed amount, 252.3 atmospheres, to the pressure uniformly distributed over the surface. This is considerably in excess of the critical pressure (217.8 atm.) of water.

The vital point in isostasy is that at 374°C. 13.7 per cent of the water was deposited as fluid upon the earth's surface, 86.3 per cent remaining in the air. This fluid suddenly deposited amounted to sufficient to cover the entire earth to a depth of 357 meters or 1171 feet. Local pressures (at the lowest point) may well have amounted to 3000 feet or more of water. This discontinuity in pressure was pointed out and discussed in a paper by the writer in Science, October 6, 1911. Not alone as regards isostasy but chemically and geologically, this abrupt precipitation of a seventh of the earth's water at such an elevated temperature and tremendous pressure must have been the greatest epoch marking point in the earth's geologic history. Had there been

TABLE 1.—PRECIPITATION AND PRESSURES AT VARIOUS TEMPERATURES

TEMPERATURES		PRESSURE ATMOSPHERES	$\frac{dP(\text{atm.})}{dT(\text{deg.})}$	$\frac{dP/P}{dT/T}$	VAP. PRESS. WATER (METERS)	PER CENT PRECIPITATED
°C.	Abs.					
0	273	0.006025	0.000447	20.25		100
50	323	0.1217	0.00605	16.057		100
100	373	1.000	0.0358	13.353		100
150	423	4.698	0.1272	11.452	38.21	99.53
200	473	15.34	0.3237	9.981	148.2	94.2
250	523	39.24	0.666	8.876	395.2	84.8
300	573	84.80	1.210	8.176	865.9	66.6
350	623	163.21	2.000	7.634	1676	35.7
370	643	207.5	2.513	7.788	2234	14.3
374	647	217.8	....	....	2240	14.1

14 per cent less water on the earth, there would have been no such great discontinuity in the earth's life.

With the exception of a few metals, all minerals (even quartz) give way before water at or near its critical temperature and pressure. The first solid crust to form, namely the carbides freezing[2] at 4600 to 4900°, could last but a short time while the oxides, forming at lower temperatures, would rapidly become hydrated and attack each other. Solution and erosion would proceed at enormous rates.

At temperatures below 374° precipitation rapidly increases with lowering of (mean annual) temperatures as shown in Table 1. For example at 300°C. the water is $\frac{2}{3}$ precipitated as fluid on the earth's surface while the remainder, equivalent to a column 865.9 meters high, is vaporized and constitutes over 98 per cent of the pressure of the

[2] WILLIAM R. MOTT. Trans. Amer. Electrochem. Soc., p. 255, 1918.

atmosphere. Some writers have wrongly assumed that at temperatures just above 100°C. the oceans would have all left the earth. Such is far from being the case. Even at 200°C. only 6 per cent of the water would be vaporized.

Pressure due to other components than water vapor and the permanent gases considered above would lower the proportion of water vaporized given in the table. However very few substances (mercury, sulphur, CO_2, SO_2 . . .) have a vapor pressure as high even as one atmosphere at 374° and these are either too scarce to need consideration or are locked up in compounds of still lower vapor or dissociation pressures.

When the water was all vaporized the atmosphere was of course very much deeper than at present, water vapor extending out perhaps 1000 miles or $\frac{1}{4}$ the earth's radius. Although heavily blanketed by material of low heat conductivity, conditions were favorable for steep thermal gradients in the outer layers and therefore for copious local (high level) precipitation. It is very doubtful whether such rain ever reached the surface. The thermal gradient from poles to equator was probably slightly less than at present.

Water has been chosen as an example because of its abundance and the simplicity of its behavior. Nearly complete data of high precision are available and anyone with a knowledge of elementary physics can rough out the problem. The molecular weight of water differs but little from that of the nitrogen-oxygen atmosphere so there is but little tendency to segregation. Nor are there other abundant substances having closely related thermal properties to complicate matters.

Next to be considered are the oxides of iron (7 per cent), aluminum (15 per cent) and silicon 60 per cent of the earth's crust 10 miles deep according to F. W. Clarke as compared with 7 per cent for water. Both SiO_2 and Al_2O_3 reach a vapor pressure of about one atmosphere at about 2200°C. with dissociation into oxygen and metal already in an advanced stage. It appears highly probable that these oxides are completely dissociated at temperatures far below those at which any considerable fraction would be vaporized. At high temperatures therefore we have to consider not fused and vaporized oxides but oxygen and fused metals with their vapors. Since the mass of the oxygen is about 7 times that of the water present on the earth, atmospheric pressure at 3000 to 3500° would be about 2000 atmospheres or 15 tons per square inch. Oxygen would reside at all levels since there would be but little tendency to segregate. The heavy metallic vapors (of Si, Al, Fe, Mg, Ca and Na) on the other hand would

tend to remain largely near the surface on account of their higher molecular weights. In this temperature region (3000–3500°) gases and vapors also become ionized by thermal agitation and therefore self luminous and good radiators of short wave radiation. This would tend to equalize temperatures by more rapid heat exchange. There was no precipitation of fluids from the outer cooler portions of the atmosphere upon the surface of the earth.

In summary, the history of the earth and of other planets of similar composition may be thus sketched out on a temperature rather than a time scale.

1. At 5000° and above. No solids present. Atmospheric pressure 20 to 30 tons per square inch. The atmosphere over 90 per cent oxygen with water vapor and free hydrogen in the outer layers and metallic vapors near the surface.

2. 4800 to 4600°. First solid crust formed consisting of metallic carbides, probably in thin scattered patches. Atmosphere as above.

3. 4600 to 3000°. But little variation in conditions. Luminosity decreasing rapidly with temperature. A few more carbides became solid. Practically no other compounds in any state except liquid alloys.

4. 3000 to 2000°. This is the great period of oxydation. Hydrogen and the more abundant metals first form stable oxides. All or nearly all in a molten condition with only water vaporized to a large extent.

Atmospheric pressure drops from about 20 to about 3 tons per square inch due to removal of nearly all the free oxygen from the gaseous state. But for the protective action of the superficial layer of oxides formed but very little oxygen would have been left. The amount of water formed limited by the amount of hydrogen present.

5. 2000 to 400°. This wide range like 3, was one of many minor changes but with little outstanding. A thick crust of oxides chiefly silica and silicates is being formed with some chlorides and sulphides. The original scanty patchy crust of metallic carbides probably deeply buried by silicate minerals. Water still all vaporized and not effective for hydration of surface minerals.

6. 374°. One seventh of the water precipitated to the surface as fluid. Atmospheric pressure dropping abruptly from 3700 to 3200 pounds per square inch. This water (sufficient to cover the entire earth 1170 feet deep) would accumulate in the lowest levels probably half a mile deep.

7. 374 to 300°. This is the period of hydration, solution, erosion, chemical changes and mineral formation, all proceeding at a rate

difficult of conception. Metallic oxides are hydrated to acids and alkalis in enormous quantities. All forms of silica and silicates are soluble and play a major rôle (in a minor key). Carbides are of course decomposed wherever water can reach them, the final result presumably being carbon dioxide. Within this temperature range the ocean increased to 4 times its initial, and $\frac{2}{3}$ its present volume. Torrential rains of almost red hot water at very high pressures changed whole landscapes over night. Sedimentation miles in thickness was a matter of but a few years instead of aeons as at present.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

THE PHILOSOPHICAL SOCIETY

931ST MEETING

The 931st meeting was held at the Cosmos Club on Saturday evening, February 6th, 1926. The meeting was called to order by Vice-President Heyl at 8:15 with 50 persons in attendance.

BYRON E. ELDRED: *Physical observations on hearing and deafness.* Helmholtz stated that the mechanical problem which the apparatus within the drum of the ear had to solve was to transform a motion of great amplitude and little force, such as impinges on the drumskin, into motion of small amplitude and great force such as had to be communicated to the fluid of the labyrinth. Were this the only problem the ear of the bird would best serve the purpose as it provides the simplest mechanism:—that of the large and small diaphragm connected by a single rigid member. The ossicular arrangement is Nature's device for slow moving animals. It serves the further purpose and solves another problem of regulating the force imparted to the labyrinthian fluid.

The human drum apparatus may be considered to function as a variable transformer. In normal hearing there is accommodation for varying force of air wave vibration. This accommodation or adjustment for reception is explained by the functioning of the tensor tympani muscle in response to the indicating nerves of the external layer of the drumhead.

Failure in accommodation of the muscle control is emphasized as the probable cause of ordinary deafness uncomplicated by disease. Otosclerosis is suggested as a more probable result of deafness than its cause. Movable joints in the human system consigned to extended temporary inaction become sclerosed.

A minimum of force of air wave vibration is required for hearing in a normal person and greater force for one of defective hearing. The drumskin collects the resultant force of many air wave vibrations which are transmitted to the ossicles as a compound mechanical vibration to become in the perilymph varying pressures in liquid where analysis takes place into the simple vibrations which afford the sense of hearing.

Certain sustained noise vibrations furnish the force required for many deaf persons. Ordinary speech combines with these noise vibrations and is heard.

The force vibration may be one of inaudible frequency and effect the same result. If the force waves are too strong, then the deaf ear, by accommodation protects itself against this force and the ability to hear normal voice is lessened. The compounded vibration is evidently diminished in force. This explains the difficulty experienced with normal hearing under noise conditions.

If a substantially sinusoidal air wave vibration of suitable force is furnished certain deaf people experience sustained hearing ability for hours after a few minutes exposure to the wave. Continued daily use has evidenced a cumulative effect in many cases where regular use of the instrument for several months has been resorted to, the period of better hearing extending from a few hours after the primary application of the wave to several days after the later ones.

Investigation shows that a comparatively few congenitally deaf are without some degree of hearing. It has likewise been demonstrated that most congenital deafness is due to defects of the middle ear. The results of a large scale test conducted at a public deaf mute institution have demonstrated that greatly increased hearing can be developed by the application of the peculiar wave vibration of this invention.

The theory is advanced that human infants are born protected against inner ear reception of vibration and it is suggested that abnormal protection may be attributed as the cause of many case of congenital deafness. (*Author's abstract.*)

H. A. MARMER, *Recording Secretary.*

SCIENTIFIC NOTES AND NEWS

The Ore Deposits Club met at the Geological Survey on March 26 to discuss informal contributions on the subject of *Field methods and equipment.*

At the regular meeting of the Columbia Historical Society on April 20 Dr. EDGAR T. WHERRY gave an illustrated lecture on *Wild flower cultivation.*

The regular April meeting of the Petrologists' Club, held at the Geological Survey on April 6, was devoted to a discussion of *The rôle of water in magmas.* The discussion was opened by G. W. MOREY of the Geophysical Laboratory.

The Pick and Hammer Club met at the Geological Survey on March 27. E. F. BURCHARD outlined his visits to iron and manganese ore deposits in several South America countries, and J. T. SINGEWALD of Johns Hopkins University described his 1925 exploration of the headwaters of the Amazon in Peru.

Dr. J. G. THOMSON of the London School of Tropical Medicine, exchange Professor with Johns Hopkins Medical School, Baltimore, Md., visited laboratories of the Bureau of Animal Industry and the Bureau of Plant Industry, and attended the 95th meeting of the Helminthological Society of Washington, Saturday night, April 18, 1926.

J. E. SANDERS, JR., magnetic observer of the Carnegie Institution of Washington, cabled his arrival on April 22, at Cotonou, Dahomey, after a successful series of magnetic observations along the Niger River in French West Africa.

Dr. A. C. LAWSON has been appointed to represent the American Geophysical Union at the Fourteenth International Geological Congress, at Madrid, May 26–30, 1926.

Amundsen's ship *Maud* was recently purchased by the Hudson's Bay Company and renamed the *Baymaud*. She is to be used near Boothia Felix.

JOHN LINDSAY has been appointed delegate from the Carnegie Institution of Washington to the Pan-American Congress at Panama City, June 18–25, 1926.

Dr. C. G. ABBOT, Assistant Secretary of the Smithsonian Institution, has just returned from a six months journey to Algeria, Baluchistan, and Southwest Africa for the purpose of selecting a location for a solar observatory to measure the variations of the sun. This project is under the auspices of the National Geographic Society which is supplying the funds for erecting and maintaining the observatory for four years.

Dr. ABBOT has chosen Mt. Brukkaros, altitude 5200 feet, situated about 60 miles to the northwest of Keetmanshoop, Southwest Africa. The rainfall in this region averages 3½ inches a year; the clearness is extraordinary, and the prospects for fair observing weather are regarded by him as superb.